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(54) Title: <b>ASP<sup>B28</sup> INSULIN CRYSTALS</b>			
(57) Abstract  The present invention relates to insulin crystals comprising Asp <sup>B28</sup> and protamine, and pharmaceutical preparations containing same. The crystals and preparations exhibit rapid onset and prolonged activity when administered in vivo.			

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## ASP<sup>B28</sup> INSULIN CRYSTALS

### INTRODUCTION

The present invention relates to crystals of Asp<sup>B28</sup> human insulin and to preparations containing such crystals.

### 5 THE TECHNICAL FIELD

Diabetes is a general term for disorders in man having excessive urine excretion as in diabetes mellitus and diabetes insipidus. Diabetes mellitus is a metabolic disorder in which the ability to utilize glucose is more or less completely lost. About 2% of all people suffer from diabetes. If a diabetic patient is not treated properly, diabetes  
10 mellitus results in hyperglycemia giving symptoms like thirst, hunger, emaciation and weakness. Diabetes also gives rise to imperfect metabolism of fats with resulting acidosis, sometimes leading to dyspnoea, lipidemia, ketonuria and, finally, coma. Diabetes mellitus is frequently associated with progressive weakening of the small vessels, particularly by affecting the eye and kidney, and atherosclerosis, and there  
15 may also be lowered resistance to pyrogenic infections. Patients having no or too low production of insulin can be treated with insulin preparations.

In the treatment of diabetes mellitus, many varieties of insulin preparations have been suggested and used. As diabetic patients are treated with insulin for several decades, there is a major need for safe and life quality improving insulin  
20 preparations. Some of the commercial available insulin preparations are characterized by a fast onset of action and other preparations have a relatively slow onset but show a more or less prolonged action. Fast acting insulin preparations are usually solutions of insulin, while retarded acting insulin preparations can be  
25 addition of zinc salts alone or by addition of protamine or by a combination of both.

In addition, some patients are using preparations having both a fast onset of action and a more prolonged action. Such a preparation may be an insulin solution wherein protamine insulin crystals are suspended. Some patients do themselves prepare the final preparation by mixing an insulin solution with a suspension preparation in the  
5 ratio desired by the patient in question.

Normally, insulin preparations are administered by subcutaneous injection. What is important for the patient, is the action profile of the insulin preparation which is the action of insulin on the glucose metabolism as a function of the time from the injection. In this profile, inter alia, the time for the onset, the maximum  
10 value and the total duration of action are important. A variety of insulin preparations with different action profiles are desired and requested by the patients. One patient may, on the same day, use insulin preparations with very different action profiles. The action profile requested is, for example, depending on the time of the day and the amount and composition of any meal eaten by the patient.

## 15 BACKGROUND ART

The first stable neutral insulin suspension was developed by Scott and Fischer (J.Pharmacol.Exp.Ther. 58 (1936), 78) who discovered that the presence of a surplus of protamine and a zinc salt (2  $\mu$ g zinc per IU (international Unit) insulin) could stabilize the protamine insulin preparation, described by Hagedorn et al.:  
20 J.Am.Med.Assn. 106 (1936), 177 - 180.

Protamine Zinc Insulin made according to the United States or European Pharmacopoeias contains amorphous protamine zinc insulin as well as crystalline Protamine Zinc Insulin. Freshly prepared protamine zinc insulin contains mainly amorphous precipitate which will partly be transformed into crystalline particles  
25 upon storage, leading to a more protracted effect.

A completely crystalline protamine zinc insulin modification designated NPH insulin or Isophane Insulin was developed by Krayenbühl and Rosenberg (see

Rep.Steno Mem. Hosp.Nord.Insulinlab. 1 (1946), 60; and Danish patent No. 64,708). They found that insulin and protamine brought together in isophane proportions at a neutral pH value in the presence of a small amount of zinc and phenol, or a phenol derivative, preferably m-cresol, will form an amorphous precipitate which upon standing is gradually but completely transformed into oblong tetragonal crystals limited at the ends by pyramidal faces. Insulin and salmon protamine co-crystallize in a weight ratio corresponding to about 0.09 mg protamine sulphate per mg insulin. Zinc in an amount of at least 3.5  $\mu$ g per mg insulin and a phenol in a concentration higher than 0.1% is necessary for the preparation of the tetragonal crystals.

In the early days, this kind of crystals were prepared using porcine and bovine insulin from natural sources, but from the eighties, also human insulin, made by genetic engineering or by semisynthesis, is used.

Human insulin consists of two polypeptide chains, the so-called A and B chains which contain 21 and 30 amino acids, respectively. The A and B chains are interconnected by two cystine disulphide bridges. Insulin from most other species has a similar constitution, but may not contain the same amino acids at corresponding positions in the chains as in human insulin.

The development of the process known as genetic engineering has made it possible easily to prepare a great variety of insulin compounds being analogous to human insulin. In these insulin analogues, one or more of the amino acids have been substituted with other amino acids which can be coded for by the nucleotide sequences. As human insulin, as explained above, contains 51 amino acid residues, it is obvious that a large number of insulin analogues is possible and, in fact, a great variety of analogues with interesting properties have been prepared. In human insulin solutions with a concentration of interest for injection preparations, the insulin molecule is present in associated form as a hexamer (Brange *et al.*: Diabetes Care 13, (1990), 923 - 954). After subcutaneous injection, it is believed that the rate of absorption by the blood stream is dependent of the size of the molecule, and it

has been found that insulin analogues with amino acid substitutions which counteract or inhibit this hexamer formation have an unusual fast onset of action (Brange *et al.*: *Ibid*). This is of great therapeutic value for the diabetic patient.

In the crystals of the prolonged acting protamine insulin preparations, the insulin is also found to be hexameric (Balschmidt *et al.*: *Acta Chryst.* B47, (1991), 975 - 986) and as far as we are aware, no examples on crystallization of genetic engineered or (semi)-synthetic prepared low associating insulin analogues with protamine have been published hitherto.

One object of this invention is to prepare protamine containing crystals of a low associating insulin analogue which conveniently can be used for insulin preparations.

Another object of this invention is to prepare protamine containing insulin analogue crystals which enables mixed preparations having both a very rapid onset of insulin action and a prolonged insulin action.

#### BRIEF STATEMENT OF THIS INVENTION

Surprisingly, it has been found that when combining the insulin analog Asp<sup>B28</sup> human insulin which is almost monomeric in solution (Brange *et al.*: *Ibid*) with protamine in the presence of small amounts of zinc and a phenol, it is possible to prepare NPH insulin like crystals which fulfil the physical requirements for suspension preparations, i.e. slowly sedimentation and easy resuspension. In contrast, for example, it has not been possible to prepare a suitable suspension of crystals of another very similar insulin analogue, the Glu<sup>B28</sup> human insulin, which structurally only differs from the Asp<sup>B28</sup> analogue by an additional methylene group in the amino acid side chain.

## DETAILED DESCRIPTION OF THIS INVENTION

One aspect of this invention is crystals comprising Asp<sup>B28</sup> human insulin and protamine. If desired, said crystals also contain zinc. Another aspect of this invention is pharmaceutical preparations comprising crystals comprising Asp<sup>B28</sup> human insulin, 5 protamine and, if desired, zinc. Said preparations are preferably in an aqueous medium.

Protamine is the generic name of a group of strongly basic proteins present in sperm cell nucleic in saltlike combination with nucleic acids. Commercially available protamines can be isolated from mature fish sperm and are usually obtained as the 10 sulphate. The peptide composition of a specific protamine may vary depending of which family, genera or species of fish it is obtained from. Normally, protamines to be used together with insulin are obtained from salmon (salmine) or rainbow trout (iridine). Protamine from salmon or trout can be separated into two or three main fractions of proteins which may be separated further. The different parent peptides 15 consist of about 30 amino acids of which more than 20 are arginines. The average molecular weight of protamine is about 4,300. Preferably, protamine sulphate of high purity is used.

In a preferred embodiment of this invention, the content of protamine in the crystals of this invention is in the range from about 10 to about 15% (weight/weight) 20 of protamine, preferably from about 12.5 to about 14 % (weight/weight) of protamine.

The content of zinc in the crystals and preparations of this invention may wholly or partially originate from a zinc salt such as zinc chloride, zinc sulphate or zinc acetate which is added during the manufacturing of the preparations.

25 In a preferred embodiment of this invention, the content of zinc in the crystals of this invention is in the range from about 0.35 to about 1.5% (weight/weight) zinc, preferably from about 0.5 to about 1% (weight/weight) zinc. In

another preferred embodiment of this invention, the total content of zinc (in bound and, optionally, in free form) in the preparation of this invention is in the range from about 0.3  $\mu\text{g}$  through about 2  $\mu\text{g}$  zinc per IU of Asp<sup>B28</sup> human insulin.

In a further, preferred embodiment of this invention, the total content of Asp<sup>B28</sup> human insulin (in crystalline and optionally in dissolved form) in the preparations of this invention is in the range from about 10 through about 500 IU/ml, preferably in the range from about 20 through about 200 IU/ml, most preferred in the range from about 40 through about 100 IU/ml.

In a further, preferred embodiment of this invention, the preparations of this invention have a pH value in the range from about 6.5 through about 8, preferably in the range from about 7 through about 7.5, most preferred in the range from about 7.2 through about 7.4.

In a still further, preferred embodiment of this invention, the crystals and preparations of this invention contain phenol or a derivative thereof such as m-cresol acetic acid ester. In said crystals, the phenol or phenol derivative is believed to be build into the crystal lattice. Probably, said crystals contain one molecule of phenol per molecule of Asp<sup>B28</sup> human insulin resulting in crystals containing about 1.5% (weight/weight) of phenol.

A preferred embodiment of this invention is preparations of this invention wherein the content of phenol or a derivative thereof is in the range from about 0.05 through about 2% (weight/volume), preferably in the range from about 0.1 through about 0.6% (weight/volume).

The crystals and the preparations of this invention can be prepared similarly to the preparation of crystals and preparations described by Krayenbühl and Rosenberg (*ibid*).



The process of crystallizing Asp<sup>B28</sup> human insulin together with protamine may be rather slow and may last for about a week. However, the resulting crystals show the usual NPH crystal appearance and size. As a consequence of the additional carboxyl group in the Asp<sup>B28</sup> human insulin molecule, the isophane ratio is substantially higher than with conventional mammalian insulins, but the high protamine content is not reflected in the subcutaneous disappearance test in pigs, as the disappearance curves of the <sup>125</sup>I-labelled Asp<sup>B28</sup> human insulin NPH crystals and human insulin NPH crystals are virtually overlapping.

Thus, Asp<sup>B28</sup> human insulin formulated as a NPH preparation is a new useful intermediately acting insulin preparation, especially when used in combination with dissolved Asp<sup>B28</sup> human insulin.

A very desired insulin preparation should exhibit both a very fast onset and a prolonged action. Such a preparation could be formulated as a mixture of a dissolved monomeric insulin analogue and a suspension of human insulin NPH crystals. Unfortunately, such a preparation has turned up not to be stable, as an exchange between the human insulin in the crystals and the dissolved insulin analogue slowly takes place and thus impairs the very fast acting properties of the preparation.

A preparation containing exclusively Asp<sup>B28</sup> human insulin both in the dissolved phase and in the NPH crystals are stable and have shown to exhibit a very rapid onset of absorption as well as a prolonged absorption by the subcutaneous disappearance test of a <sup>125</sup>I-labelled preparation in pigs.

Such a preparation can be produced in a manner known per se, for example, by mixing a suspension of Asp<sup>B28</sup> human insulin NPH crystals with a solution of Asp<sup>B28</sup> human insulin. The ratio of such mixtures may be from about 10% to about 50%, preferably about 30% insulin analogue solution and from about 50% to about 90%, preferably about 70% insulin analogue crystals suspension. Consequently, a preferred embodiment of this invention is a preparation of this invention containing both dissolved Asp<sup>B28</sup> human insulin and crystals comprising Asp<sup>B28</sup> human

insulin. A still further preferred embodiment of this invention is preparations of this invention wherein the ratio between crystals comprising Asp<sup>B28</sup> human insulin and protamine, on one hand, and dissolved Asp<sup>B28</sup> human insulin, on the other hand, is in the range from about 90:10 to about 50:50, preferably about 70:30.

5 The preparations of this invention can be prepared by mixing the different constituents such as Asp<sup>B28</sup> human insulin, protamine, optionally a zinc salt, for example zinc chloride, a preservative, for example phenol, an isotonic agent, for example sodium chloride or glycerol, and a buffer, for example disodium monohydrogen phosphate, in an aqueous medium. One way of doing this is to  
10 prepare an acidic solution of Asp<sup>B28</sup> human insulin, protamine sulphate, zinc chloride, phenol and glycerol, for example by use of diluted hydrochloric acid. This solution is then slowly mixed with a sodium phosphate solution with stirring at room temperature, and after mixing, the pH value of the mixture is, if desired, adjusted to a pH value of about 7.3.

15 In a preferred embodiment of this invention, the crystals of this invention have only a minor content of amorphous material. The amorphous material may be zinc protamin phosphate or a material containing protamin and Asp<sup>B28</sup> human insulin. Bases upon the content of crystalline material containing Asp<sup>B28</sup> human insulin, the crystals of this invention preferably contain less than 10% of amorphous  
20 material containing protamin and Asp<sup>B28</sup> human insulin, more preferred less than about 5%. Bases upon the content of crystalline material, the crystals of this invention preferably contain less than 10 % of amorphous zinc protamin phosphate, more preferred less than about 5%.

Bases upon the content of crystalline material containing Asp<sup>B28</sup> human  
25 insulin, the preparations of this invention preferably contain less than 10% of amorphous material containing protamin and Asp<sup>B28</sup> human insulin, more preferred less than 5%. Bases upon the content of crystalline material, the preparations of this invention preferably contain less than 10% of amorphous zinc protamin phosphate, more preferred less than 5%.

The preparations of this invention can be used for diabetic therapy, preferably to human beings, similarly to the use of the usual commercial preparations, for example, as prescribed by the physician.

Any novel feature or combination of features described herein is considered  
5 essential to this invention.

This invention is further illustrated by the following examples which, however, are not to be construed as limiting. Mixtard is a trade mark for insulin preparations containing both dissolved insulin (rapidly acting) and suspended insulin (retarded acting). Mixtard 30/70 contains 30% of dissolved insulin and 70% of suspended  
10 insulin.

### Example 1

#### Asp<sup>B28</sup> human insulin NPH preparation:

A crystal suspension was prepared from the following two solutions:

Solution I: 197.5 mg of Asp<sup>B28</sup> human insulin, 400 of  $\mu$ l 1 N hydrochloric  
15 acid, 359  $\mu$ l of  $Zn^{++}$  solution (5 mg/ml), 2.57 ml of protamine sulphate solution (10 mg/ml), 12.5 ml of an aqueous solution containing 0.3% m-cresol, 0.13% phenol and 3.2% glycerol and water ad 25 ml.

Solution II: 5.0 ml of 0.13 M disodium monohydrogenphosphate, 12.5 ml of  
an aqueous solution containing 0.3% m-cresol, 0.13% phenol and 3.2% glycerol and  
20 water ad 25 ml.

Solution II was added to solution I and the pH value was adjusted to 7.30. The resulting suspension was left at 20°C for 24 hours followed by standing for 6 days at 4°C for complete crystallization.

### Disappearance test:

The protracted action was evaluated by the disappearance of  $^{125}\text{I}$ -labelled Asp<sup>B28</sup> human insulin NPH in comparison to  $^{125}\text{I}$ -labelled human insulin NPH after subcutaneous injection in pigs. The insulin analogue preparation was formulated as shown above with the exception that an amount of  $^{125}\text{I}$ -labelled Asp<sup>B28</sup> human insulin/human insulin, corresponding to an activity of 2  $\mu\text{Ci/ml}$  in the final preparation, has been added before the crystallization. The human insulin NPH preparation was prepared analogously. The test was set up with 6 pigs, each receiving 100  $\mu\text{l}$  of test preparation (Asp<sup>B28</sup> human insulin NPH preparation) on one side of the neck and 100  $\mu\text{l}$  standard preparation (human insulin NPH preparation) on the other side. The remaining radioactivity at the injection sites was measured at suitable intervals by external  $\gamma$ -counting.

### Results

The Asp<sup>B28</sup> human insulin NPH crystals showed the same thin rod-shaped image as in the human insulin NPH preparation and had a length of 6 - 8  $\mu\text{m}$ . The microscopic appearance of the preparation is shown at two different magnifications on the photographs in figure 1.

The subcutaneous disappearance test of the  $^{125}\text{I}$ -labelled Asp<sup>B28</sup> human insulin NPH preparation showed that the rate of disappearance from the injection site was very similar to the disappearance of the labelled human insulin NPH preparation. The  $T_{50\%}$  value (i.e. the time for 50% remaining radioactivity) was found to be  $10.1 \pm 1.0$  hours versus  $10.9 \pm 0.9$  hours for the standard NPH preparation (human insulin). The results are illustrated in graphic form in figure 2.

### Conclusions

Asp<sup>B28</sup> human insulin has been found able to crystallize with protamine by the usual NPH preparation procedure, but standing for a week was necessary for complete crystallization. The resulting crystal suspension had the usual appearance  
5 known from the human insulin NPH preparation.

Evaluated by a subcutaneous disappearance test in pigs, the action profile of the Asp<sup>B28</sup> human insulin NPH preparation was not found different from a human insulin NPH preparation.

### Example 2

#### 10 Mixed dissolved and NPH preparation of Asp<sup>B28</sup> human insulin:

A crystal suspension was prepared from the following two solutions:

Solution I: 158.1 mg of Asp<sup>B28</sup> human insulin, 130  $\mu$ l of 1 N hydrochloric acid, 142  $\mu$ l of Zn<sup>++</sup> solution (10 mg/ml), 2.087 ml of protamine sulphate solution (10 mg/ml), 2.0 ml of an aqueous solution containing 3% phenol and 16% glycerol  
15 and water ad 25 ml.

Solution II: 4.0 ml of 0.13 M disodium monohydrogen phosphate, 2.0 ml of an aqueous solution containing 3% phenol and 16% glycerol and water ad 25 ml.

Solution II was added to solution I and the pH value was adjusted to 7.30. The resulting suspension was left at 20°C for 24 hours followed by standing for 6  
20 days at 4° for complete crystallization.

A solution was prepared by dissolving 39.5 mg of Asp<sup>B28</sup> human insulin in 2 ml of water by addition of 32  $\mu$ l of 1 M hydrochloric acid and then 7.4  $\mu$ l of Zn<sup>++</sup>

solution (10 mg/ml), 1.0 ml of an aqueous solution containing 3% phenol and 16% glycerol, 1.0 ml of 0.13 M disodium monohydrogen phosphate and finally water ad 10 ml was added. The resulting pH value was 7.27.

The final mixed preparation was prepared by addition of 6 ml of the solution to 14 ml crystal suspension, thus forming a 30/70 ratio of fast acting and prolonged acting insulin analogue.

After standing over night at 20°C, the relative amount of dissolved protein in the supernatant was determined by reversed phase HPLC.

#### Disappearance test:

10 The action profile was evaluated by the disappearance of  $^{125}\text{I}$ -labelled Asp<sup>B28</sup> human insulin from the mixed Asp<sup>B28</sup> human insulin preparation in comparison to the disappearance of  $^{125}\text{I}$ -labelled human insulin from a human insulin Mixtard® 30/70 preparation after subcutaneous injection in pigs. The Asp<sup>B28</sup> human insulin preparation was formulated as shown above, with the exception that an amount of  
15  $^{125}\text{I}$ -labelled Asp<sup>B28</sup> human insulin analogue, corresponding to an activity of 1.7  $\mu\text{Ci/ml}$  in the final preparation, has been added together with the cold analogue. The human insulin Mixtard 30/70 preparation was prepared analogously. The test was set up as described in example 1.

#### Results:

20 The mixed Asp<sup>B28</sup> human insulin preparation showed a similar relative amount of dissolved protein in the supernatant as in a human insulin Mixtard® 30/70 preparation when analyzed by reversed phase HPLC.

The subcutaneous disappearance test of the mixed Asp<sup>B28</sup> human insulin preparation showed that the rate of disappearance from the injection site was substantially faster during the first hours than for the human insulin Mixtard<sup>®</sup> preparation, but later the rates became very similar. The T<sub>75%</sub> value (i.e. the time for 75% remaining radioactivity) for the mixed Asp<sup>B28</sup> human insulin preparation was found to be  $1.6 \pm 0.5$  hours versus  $2.2 \pm 0.5$  hours for the human insulin Mixtard<sup>®</sup> standard. The T<sub>50%</sub> values were found to  $4.9 \pm 1.0$  hours versus  $5.7 \pm 1.0$  hours and the T<sub>75%</sub> values to  $12.8 \pm 2.3$  hours versus  $13.4 \pm 2.4$  hours, respectively. The results are illustrated in graphic form in figure 3.

<sup>10</sup> Conclusions:

It has been possible to formulate a mixed preparation of dissolved Asp<sup>B28</sup> human insulin and NPH crystallized Asp<sup>B28</sup> human insulin which by a subcutaneous disappearance test in pigs have shown a substantially faster initial and a similar prolonged absorption profile as found for a standard human insulin Mixtard<sup>®</sup> 30/70 preparation.

## PATENT CLAIMS

1. Crystals comprising Asp<sup>B28</sup> human insulin and protamine.
2. Crystals, according to Claim 1, comprising zinc.
3. Crystals, according to Claim 1 or 2, comprising from about 0.35 to  
5 about 1.5, preferably from about 0.5 to about 1, % (weight/weight) zinc.
4. Crystals, according to any one of the preceeding claims, comprising  
from about 10 to about 15, preferably from about 12.5 to about 14, %  
(weight/weight) of protamine.
5. A preparation comprising crystals according to any one of the  
10 preceeding claims suspended in an aqueous medium.
6. A preparation, according to Claim 5, comprising zinc.
7. A preparation, according to any one of the Claims 5 or 6, wherein the  
content of Asp<sup>B28</sup> human insulin is in the range from about 10 through about 500  
IU/ml, preferably in the range from about 20 through about 200 IU/ml, most  
15 preferred in the range from about 40 through about 100 IU/ml.
8. Protamine zinc insulin preparation, according to any one of the Claims  
5 through 7, wherein the content of zinc is in the range from about 0.3  $\mu$ g through  
about 2  $\mu$ g zinc per IU of Asp<sup>B28</sup> human insulin.
9. A preparation, according to any one of Claims 3 through 8, having a  
20 pH value in the range from about 6.5 through about 8, preferably in the range from

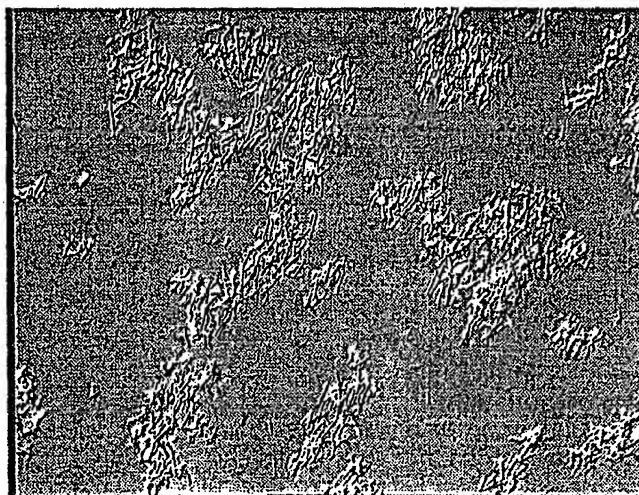


about 7 through about 7.5, most preferred in the range from about 7.2 through about 7.4.

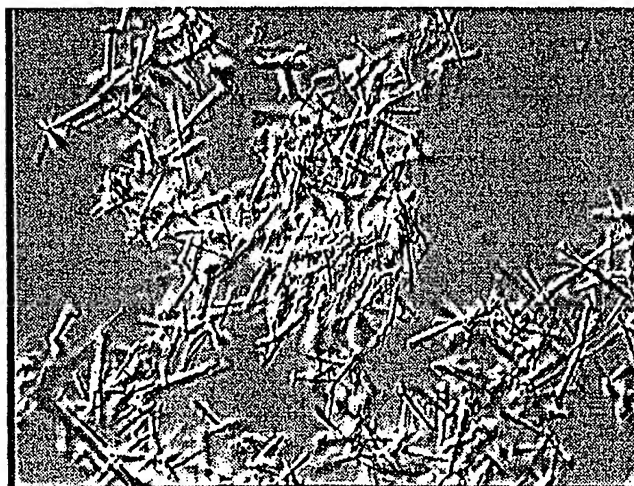
10. A preparation, according to any one of the Claims 5 through 9, comprising dissolved Asp<sup>B28</sup> human insulin.

11. A preparation, according to the preceding claim, wherein the ratio between crystals comprising Asp<sup>B28</sup> human insulin and protamine, on one hand, and dissolved Asp<sup>B28</sup> human insulin, on the other hand, is in the range from about 90:10 to about 50:50, preferably about 70:30.

12. Any novel feature or combination of features described herein.



10  $\mu$ m



10  $\mu$ m

FIG. 1

2/3

# S.c. Disappearance Test in Pigs

100  $\mu$ l 0.6 mM  $^{125}$ I-labelled NPH-prep

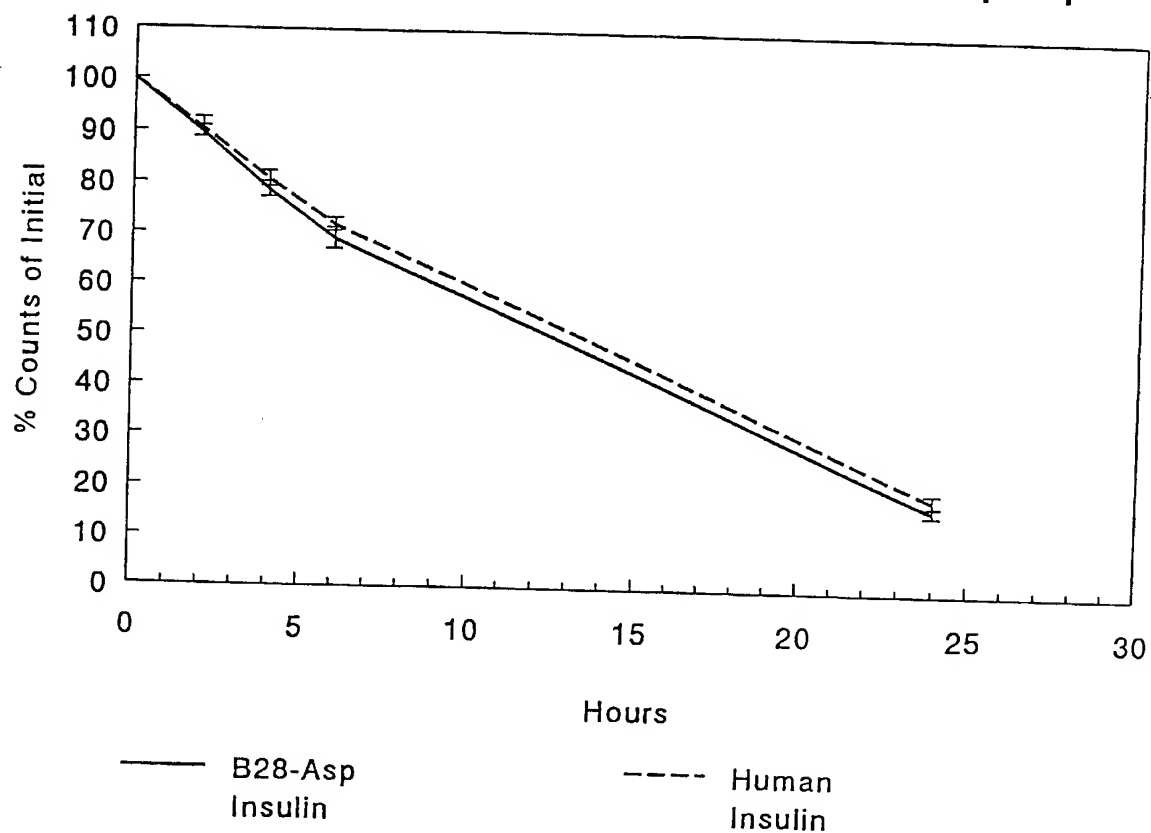


FIG. 2

3/3

# S.c. Disappearance Test in Pigs

100  $\mu$ l 0.6 mM  $^{125}$ I-labelled Mix-prep

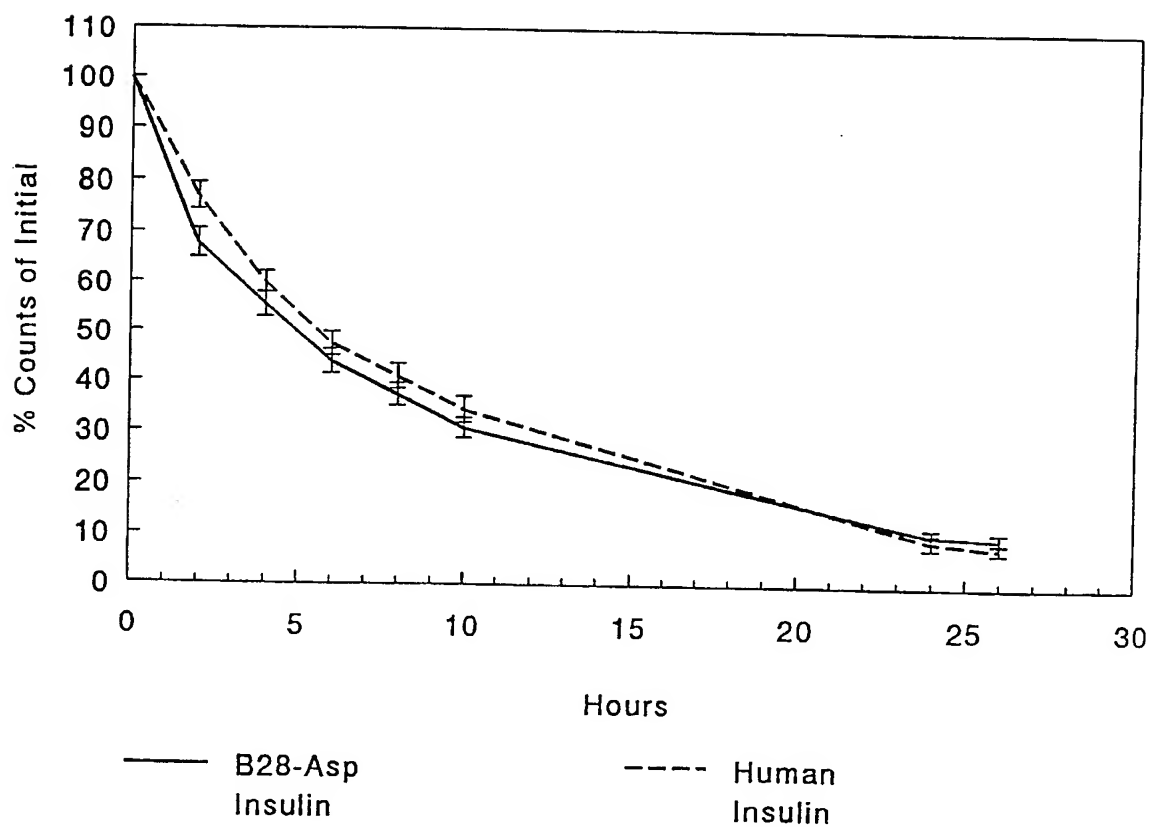


FIG. 3

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/DK 94/00246

## A. CLASSIFICATION OF SUBJECT MATTER

IPC : C07K 7/40, C07K 7/42, A61K 37/26 // C07K 99:26  
According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC : A61K, C07K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

MEDLINE, BIOSIS, EMBASE, WPI, CA, CLAIMS, JAPIO

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP, A2, 0214826 (NOVO INDUSTRI A/S), 18 March 1987 (18.03.87)  --	1-12
Y	DE, A1, 3327709 (HOECHST AG), 7 February 1985 (07.02.85)  -- -----	1-12

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

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**INTERNATIONAL SEARCH REPORT**  
Information on patent family members

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